Kinect Based System and Serious Game Motivating Approach for Physiotherapy Assessment and Remote Session Monitoring

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***Abstract*—This paper describes a framework focused on being a health monitoring platform as well as a source of entertainment for physiotherapy patients, particularly stroke survivors. Using the Microsoft Kinect sensor a serious game captures 3D data during the patient's session and sends it to a server. Through a web application these data can be further visualized by the physiotherapists on their assessments. Moreover, this framework intends to be a useful and effective tool for remote physiotherapy sessions allowing for a considerable cost reduction. Experimental results related to arms and shoulders rehabilitation are included in this paper.**

***Index Terms*—electronic health record, motion analysis, serious game, physical rehabilitation.**

I. Introduction

Despite being the second worldwide leading cause of death according to the World Health Organization (WHO), stroke disease consequences are still overlooked. It is known that half of European stroke survivors make an incomplete recovery and that half of them need continuous assistance in the daily life [1].

Although it is indispensable for improving motor disabilities and quality of life, physiotherapy is often a slow, painful and high cost process requiring motivation that is often difficult to achieve. Some studies have identified serious games as an effective tool to fight against the discouragement provoked by the monotony of the exercises [2], [3]. The most novel approach is the use of virtual and augmented realities, creating a more enthusiastic interaction between the user and the application. In some cases of stroke rehabilitation, it was noticed that there is a higher chance of improvement for patients using this technology as training appears to be more challenging, intensive and task-specific motivating [4].

Nowadays, the world is moving towards a convergence of data and the emergence of Smart Cities is a natural consequence of such behavior. In a Smart City background [5], remote therapy can be helpful for allowing home environment monitored sessions and even some cost reduction.

Furthermore, physiotherapists' registering and assessment capabilities are very important in the patient rehabilitation. Normally, the evaluation of the patients' improvements is made by direct observation. In order to assure an objective evaluation of the rehabilitation progress the usage of sensors that extract the motion information in unobtrusive way followed by appropriate motion analysis can be a good solution. In this context, the paper promotes a physiotherapy assessment framework that includes a 3D serious game as well as a web application which offers quantitative information about the patient's performance during therapy sessions. Although some work has been done on this subject, [3], [6]–[9], most current solutions differ from ours in two points. Firstly, they usually involve intrusive sensors, which are normally expensive and not well received by the patients. Secondly, the Electronic Health Record component that we include is mostly underestimated or not explored by others.

II. Related Work

There are several approaches which can be taken for capturing humans' spatial data while exercising. Vicon [10] commercializes high precision systems for optical motion capture capable of retrieving information about a body's velocity, distance and joints' angles. Nevertheless, besides being very expensive [11], this approach requires markers or sensors attached to the user which are difficult to calibrate and provoke discomfort.

Other intrusive, however less costly solutions involve techniques such as electromyography, where the electrical activity in a subject's body is used for muscular monitoring [12], and accelerometry-based ones, where accelerometers are bonded to the user's body enabling the collection of motion data [13]. Arteaga et al. [13] analyzed the posture of stroke survivors with this technique.

A common source of human tracking sensors are the ones developed by the video game industry. Tanaka et. al. [14] studied and compared the reliability of Microsoft Kinect, Sony PlayStation Move and Nintendo Wii systems for rehabilitation

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purposes. Their availability combined with their low price gives them an important advantage in medical applications. Deutsch et. al. [15] studied the evolution of a patient with cerebral palsy while performing several sessions playing Nintendo Wii. Although improvements were obvious, these games were not made for rehabilitation purposes, therefore they lack of technical data which can help physiotherapy assessments.

From the low cost solutions, Kinect is a non-intrusive one and seems appropriate for motion analysis in medical applications. Furthermore, several studies had confirmed that although presenting expected discrepancies, this sensor achieves competitive tracking measurements compared with high precision optical systems [11], [16], [17].

Regarding Kinect, research has been made on physiotherapy gaming applications using this sensor. Rahman et. al. [6] used Kinect to interact with the well-known Second Life virtual world [18] to record physiotherapy sessions. In another work [3], five games from Kinect Adventures were played in order to restore some functionalities in a patient with a history of traumatic brain injury. Although the benefits of virtual reality were highlighted in both, these games were not made for physiotherapy purposes so they are less efficient for the patient's rehabilitation and do not provide useful information about the patient's performance.

Moreover, some serious games were developed specifically for physiotherapy [2], [8], [9], [19]–[22]. Although these approaches were identified as a source of encouragement for patients, some of them lack of integration with a web application enabling remote sessions to be hereafter analyzed [2], [8], [19], [20] and the others does not provide significant technical information which can help the physiotherapy assessment [9], [21], [22].

Frameworks such as the ones previously referred can be easily integrated in a Smart Health environment. Therefore, inserted in such a networked context, our solution enables an increase of efficiency and service quality and a consequent decrease in costs [5], [23]–[25].

III. Remote Physiotherapy System Overview

Our framework is composed by three main independent modules: a serious game, a web application and an intermediate server. The middle server's purpose is to provide an interface between the other two modules and the database managed by a Microsoft SQL Server. A .NET Web Service [26] is available for enabling simple communication between the modules. The serious game was developed using Unity 3D [27] and C# scripting. It uses Kinect sensor to capture the patient's data and sends it to the database through the middle server. Finally, the web application's aim is to allow a simple visualization of the data stored about the patient's performance mainly through the use of charts. It is also built using Microsoft technology, more specifically ASP.NET [28].

Figure 1 represents the global architecture of the proposed system. The three modules interact through an Internet connection. Patients and physiotherapists are the two kind of users defined. While playing the serious game the first type

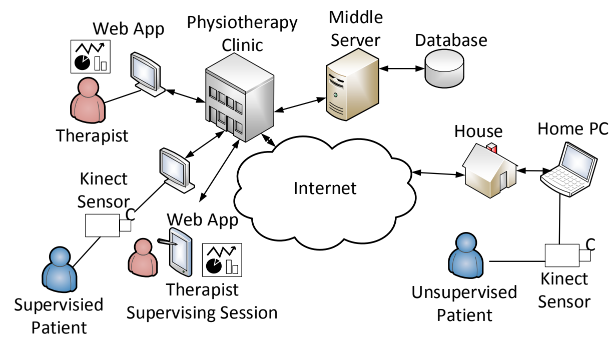


Fig. 1. System global overview.

of users interacts with the system and technical data about the gestures performed is recorded. It is possible that the sessions are performed in some health facilities with the patient being under supervision or in a home environment without supervision, such as it is shown in figure 1. Either way, the user's experience is the same. Following this, the therapists access this information through the web application, using a computer or a tablet. The patient's motion data is presented through charts. A report is generated allowing for the physiotherapists to use this system as tool for helping them in their assessments.

IV. Serious Game

Figure 2 represents a set of twenty joints captured as 3D points by the Kinects Skeletal Tracking System. This sensor was chosen because of its non-intrusive properties and its low-cost/high-precision compromise. Paavola et al. [3] analyzed the benefits of Kinect in the renewal of some functionalities in a patient with a traumatic brain injury. In this work [3], a set of games for X-box, called Kinect Adventures, was used and after some sessions improvement was observed. This might mean that existing games have the necessary properties to help in physiotherapy approaches. However, this assumption should be complemented with a precise evaluation.

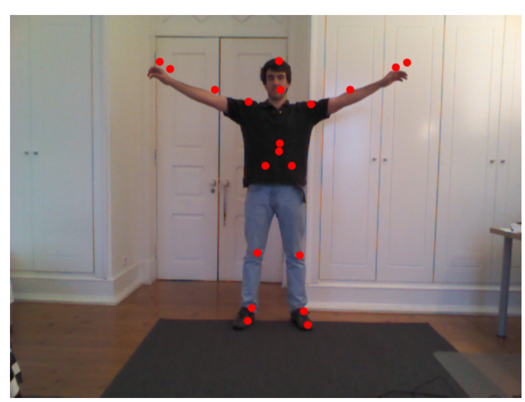
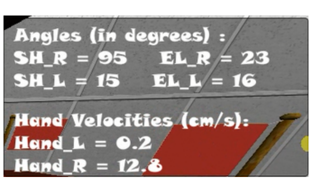


Fig. 2. Twenty tracked joints of the user's body using the Kinect Skeletal Tracking.

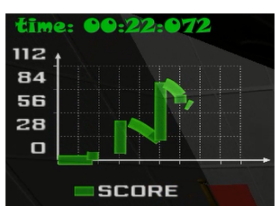
Serious games are games designed for other purposes rather than just entertainment. Following this definition, the game developed has two main purposes. Firstly it is intended to provide an entertainment factor often related with serious games [2] which has an enormous importance in providing encouragement, motivation and well-being during physiotherapy sessions. The other aim of this serious game is to provide feedback according to the patient's performed motion. The serious game does not replace the Web Application. The feedback given during the game about the user's performance is provided in order to enable self-correction while playing. A developed database will assure the physiotherapy data storage as part of an Electronic Health Record.

A screenshot of the developed serious game - *Therasoup* - is shown in figure 3. During the game, the player controls the avatar through the Kinect sensor and is supposed to pick the ingredients landed in shelves and to put them in a pan at the center, such as it can be observed in figure 3(a). This game tries to simulate a daily life activity such as cooking. The box in the bottom-left corner indicates with a semaphore if any hand has an object attached. Moreover, the box at the top-right corner, which is shown in detail in figure 3(b), displays information about the amplitudes of the shoulders joints and the velocities of each hand in real time. Finally, the box in the top-left corner presents the playtime and the score chart. The score chart, also represented in figure 3(c), is updated in real time according to the height of the shelves reached by the player and following an exponential decay along time in order to stimulate dynamic game playing.

(a)



(b)



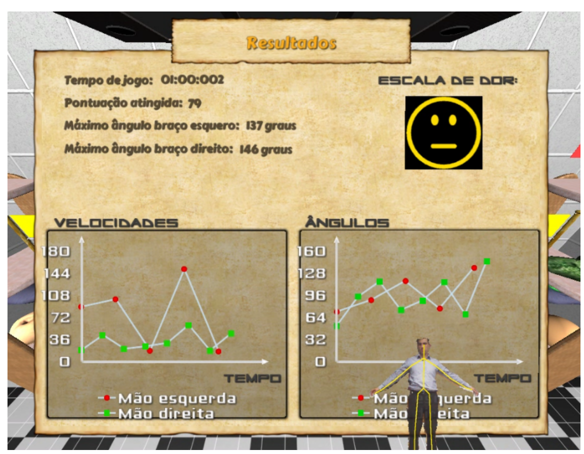
(c)

Fig. 3. *Therasoup* game-play: (a) Picking an object, (b) Shoulder amplitudes and hand velocities, (c) Time-decreasing score chart.

In the case of a patient with severe visual problems or an advanced neurological disease that cannot perceive the game because of the amount of visual information, the boxes described can be easily hidden editing game options. Although very useful for providing secondary information to the user, this information is not essential for playing the game, and without it the scenario perception can be simplified.

Furthermore, this game intends to work on two parallel skills: coordination and motor capabilities. In fact, while picking the objects from shelves and putting them in a pan the patient is improving his coordination skills. Besides this advantage, it is obviously working on a patient's physical capabilities. This serious game is focused on arms movements, more specifically in arm extension and shoulder abduction. These movements are practiced during the game. The lateral shelves are divided in three intervals of height and were chosen such that the user must perform 60, 90 and 120 degrees amplitude in the shoulder joint with the arm stretched. The frontal shelves are divided in four intervals of height and were chosen such that the user must perform 60, 90, 120 and 150 degrees amplitude in the shoulder joint with the arm stretched. As the required amplitude increases, the shelf is characterized with a flag from green to black and with a correlated increase in the score.

(a)



(b)

Fig. 4. *Therasoup* game windows: (a) Pain scale interface, (b) Rehabilitation metrics interface.

The game finishes after a specific time which can be configured in the beginning. In the end, the windows shown in figure 4 are presented to the player. Firstly, the user is asked for classifying the amount of pain felt while playing. The patient should open his right or left arm moving the bar to the right or to the left, respectively, such as it is represented in figure 4(a). After choosing the bar's value, the player should open both arms symmetrically and the window represented in figure 4(b) appears.

At this stage the patient is given some information about his performance. In the top-left corner it is possible to observe the game duration, the points scored, and the maximum amplitudes achieved by the shoulder joints. In the top-right corner there is a smiley face representing the pain felt by the user. Finally, in the bottom there are shown two line graphs. In both the x-axis represents time, the red dots refer to the left arm and the green dots refer to the right arm. Moreover, the left graph's y-axis represents the hand joints' velocities and the right graph's y-axis represents the shoulder joints' amplitudes. Each pick of an object performed during gameplay represents a different instant of time.

The information provided in the serious game must be summarized and simple to analyze. Its purpose is to motivate the patient showing a quick overview of the progress made. It can also be verified by the physiotherapist, although more detailed information can be found in the web application.

V. Web Assessment Tool

The proposed framework provides motivating physiotherapy sessions using the Kinect sensor in order to improve patients' performance overtime and at the same time provide a useful platform of health care monitoring. An electronic health record (EHR) is only useful if the data is properly displayed after being recorded in the database.

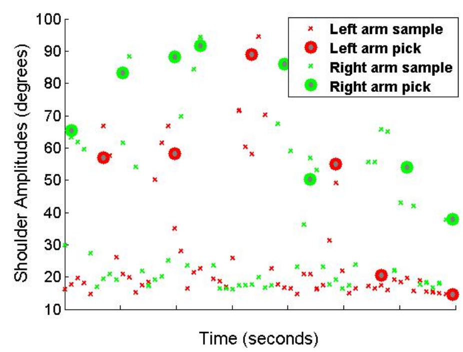
Patients and physiotherapists must be registered before using the system. This process is easily done by accessing the web application and filling a simple form. In the case of a patient, a confirmation email is sent to him. In the case of a physiotherapist register, a confirmation email is sent to the administrator since the therapist can access to several patients' personal information. Therefore, different information is displayed depending on the user.

If a patient is logged in, no complex information is shown but only simple graphs such as the ones shown in figure 4(b). On the other hand, a logged in therapist has permissions to observe any patient's information and much more technical data than the patient. Therefore, more specific graphs and charts are available. The physiotherapist can observe not only the performance in a given session, but also the evolution through several sessions. There is also the possibility to watch a recording of the patient's avatar performing the exercises. Finally, the therapist is allowed to insert amplitude constraints on any joint. In this case, the serious game will automatically adapt and will not demand the patient to reach positions which cross the constraints limits.

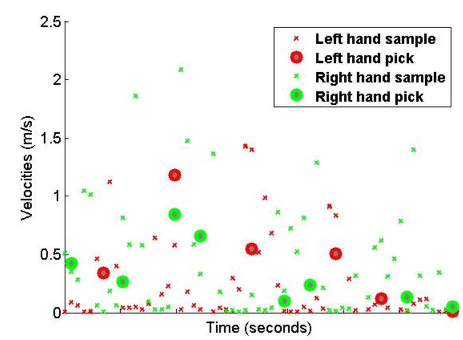
VI. Results and Discussion

As already described, during each session playing the *Therasoup* game, the user is tracked through the Microsoft Kinect sensor. All the data is sent to a server and stored in a database. Afterwards, the information referring to the user's performance can be observed. To test the proposed framework one user performed two sessions of one minute length each. During each session, information about the user's motion is captured at a constant rate of 4 samples per second. Moreover, whenever an object is picked an extra sample is taken. Graphs computed with some data from session 1 and session 2 are presented in figure 5 and 6, respectively. Points are distinguished between samples taken at a constant rate and samples taken when an object was picked. For each case, figure 5(a) and 6(a) represent the shoulder amplitudes performed by the patient while figure 5(b) and 5(b) represent the hand velocities achieved in the same instants of time.

The first session simulates a patient in an early rehabilitation stage. Looking at figure 5 the physiotherapist can easily conclude that similar maximum amplitudes and velocities were achieved for both arms. Moreover, it is possible to verify that, along time, both hand speed decrease which suggests that the patient becomes tired very quickly. This assumption is confirmed by the fact that the patient shoulder amplitudes decrease jointly with the hands' velocity. At this point, the physiotherapist can give some advice based on the information observed.



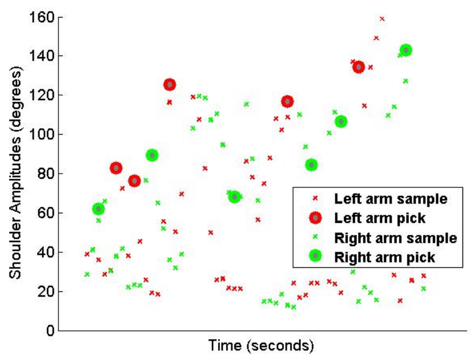
(a)



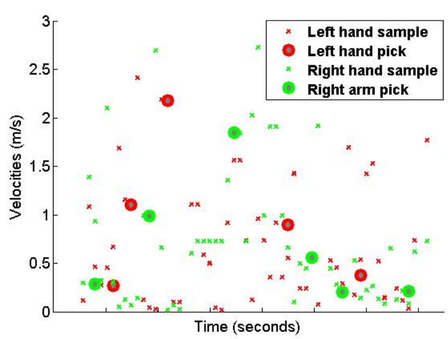
(b)

Fig. 5. Graphs representing data from session 1: (a) Shoulder joints' amplitudes evolution, (b) Hand joints' velocities graphical representation.

On the other hand, figure 6 represents the patient's data after performing session 2. In this case the physiotherapist can compare both sessions and verify if the patient improved through sessions. In a first sight, is possible to observe that, although the patient picked less objects in session 2, much higher shoulder amplitudes and hand velocities were achieved with both arms. Moreover, the speed decrease along time is related with the amplitudes increase at the same time. This means that the patient has more difficulty tho achieve higher shelves and therefore higher shoulder amplitudes.



(a)



(b)

Fig. 6. Graphs representing data from session 2: (a) Shoulder joints' amplitudes evolution, (b) Hand joints' velocities graphical representation.

There is a lot of data which can still be used to extend this analysis. For example, the elbow joints information can be used to build more graphs such as the ones developed in figure 5 and 6. Furthermore, a lot of *Key Performance Indicators* can be developed based on any information about other patient's joints. All of this data can help physiotherapists improving their assessments.

VII. Conclusions

This system aims to improve the patient's motivation while performing exercises and to provide technical data to the physiotherapist which can help in the assessment. Using the Microsoft Kinect sensor a serious game captures 3D data during the patient's session. Moreover, the patient is given feedback while playing the game. Thereafter the physiotherapist may access the information about patients using a web based information system.

This framework was presented to several physiotherapists during a workshop in Vila Nova de Gaia, Portugal. We received enthusiastic feedback as well as many suggestions. We are working to improve the design and the implementation of the web information system responsible for the data management referring to the remote physiotherapy session. Furthermore, a validation procedure will be considered possibly using other sensors, such as accelerometers and optical motion capture devices.

References

[1] T. Truelsen, B. Piechowski-Jwiak, R. Bonita, C. Mathers, J. Bogousslavsky, and G. Boysen, "Stroke incidence and prevalence in europe: a review of available data," *European Journal of Neurology*, vol. 13, no. 6, pp. 581–598, 2006. [Online]. Available: http://dx.doi.org/10.1111/j.1468-1331.2006.01138.x

[2] P. Fikar, C. Schoenauer, and H. Kaufmann, "The sorcerer's apprentice a serious game aiding rehabilitation in the context of subacromial impingement syndrome," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2013 7th International Conference on*, 2013, pp. 327–330.

[3] U. K. Paavola JM, Oliver KE, "Use of x-box kinect gaming console for rehabilitation of an individual with traumatic brain injury: A case report." J Nov Physiother 3:129, 2013.

[4] G. Saposnik, M. Levin, and for the Stroke Outcome Research Canada (SORCan) Working Group, "Virtual reality in stroke rehabilitation: A meta-analysis and implications for clinicians," *Stroke*, 2011.

[5] M. Roscia, M. Longo, and G. C. Lazaroiu, "Smart city by multi-agent systems," in *Renewable Energy Research and Applications (ICRERA), 2013 International Conference on*, Oct 2013, pp. 371–376.

[6] M. Abdur Rahman, A. M. Qamar, M. A. Ahmed, M. Ataur Rahman, and S. Basalamah, "Multimedia interactive therapy environment for children having physical disabilities," in *Proceedings of the 3rd ACM conference on International conference on multimedia retrieval*, ser. ICMR '13. New York, NY, USA: ACM, 2013, pp. 313–314. [Online]. Available: http://doi.acm.org/10.1145/2461466.2461522

[7] A. Da Gama, T. Chaves, L. Figueiredo, and V. Teichrieb, "Poster: Improving motor rehabilitation process through a natural interaction based system using kinect sensor," in *3D User Interfaces (3DUI), 2012 IEEE Symposium on*, 2012, pp. 145–146.

[8] J.-D. Huang, "Kinerehab: a kinect-based system for physical rehabilitation: a pilot study for young adults with motor disabilities," in *The proceedings of the 13th international ACM SIGACCESS conference on Computers and accessibility*, ser. ASSETS '11. New York, NY, USA: ACM, 2011, pp. 319–320. [Online]. Available: http://doi.acm.org/10.1145/2049536.2049627

[9] B. Lange, S. Koenig, E. McConnell, C. Chang, R. Juang, E. Suma, M. Bolas, and A. Rizzo, "Interactive game-based rehabilitation using the microsoft kinect," in *Virtual Reality Short Papers and Posters (VRW), 2012 IEEE*, 2012, pp. 171–172.

[10] V. M. S. Ltd. Vicon systems. [Online]. Available: http://www.vicon.com/

[11] C.-Y. Chang, B. Lange, M. Zhang, S. Koenig, P. Requejo, N. Somboon, A. Sawchuk, and A. Rizzo, "Towards pervasive physical rehabilitation using microsoft kinect," in *Pervasive Computing Technologies for Healthcare (PervasiveHealth), 2012 6th International Conference on*, 2012, pp. 159–162.

[12] S. M. Cowan, K. L. Bennell, and P. W. Hodges, "The testretest reliability of the onset of concentric and eccentric vastus medialis obliquus and vastus lateralis electromyographic activity in a stair stepping task," *Physical Therapy in Sport*, vol. 1, no. 4, pp. 129 – 136, 2000. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S1466853X00900361

[13] S. Arteaga, J. Chevalier, A. Coile, A. W. Hill, S. Sali, S. Sudhakhrisnan, and S. H. Kurniawan, "Low-cost accelerometry-based posture monitoring system for stroke survivors," in *Proceedings of the 10th International ACM SIGACCESS Conference on Computers and Accessibility*, ser. Assets '08. New York, NY, USA: ACM, 2008, pp. 243–244. [Online]. Available: http://doi.acm.org/10.1145/1414471.1414519

[14] K. Tanaka, J. Parker, G. Baradoy, D. Sheehan, J. Holash, and L. Katz, "A comparison of exergaming interfaces for use in rehabilitation programs and research," 2012. [Online]. Available: http://journals.sfu.ca/loading/index.php/loading/article/view/107/118

[15] J. E. Deutsch, M. Borbely, J. Filler, K. Huhn, and P. Guarrera-Bowlby, "Use of a low-cost, commercially available gaming console (wii) for rehabilitation of an adolescent with cerebral palsy," *Physical Therapy*, vol. 88, no. 10, pp. 1196–1207, 2008. [Online]. Available: http://ptjournal.apta.org/content/88/10/1196.abstract

[16] A. Fernandez-Baena, A. Susín, and X. Lligadas, "Biomechanical validation of upper-body and lower-body joint movements of kinect motion capture data for rehabilitation treatments," in *Proceedings of the 2012 Fourth International Conference on Intelligent Networking and Collaborative Systems*, ser. INCOS '12. Washington, DC, USA: IEEE Computer Society, 2012, pp. 656–661. [Online]. Available: http://dx.doi.org/10.1109/iNCoS.2012.66

[17] R. A. Clark, Y.-H. Pua, K. Fortin, C. Ritchie, K. E. Webster, L. Denehy, and A. L. Bryant, "Validity of the microsoft kinect for assessment of postural control," *Gait & Posture*, vol. 36, no. 3, pp. 372 – 377, 2012. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0966636212001282

[18] S. Minocha, "Introducing second life, a 3d virtual world, to students and educators," in *Technology for Education (T4E), 2010 International Conference on*, 2010, pp. 206–208.

[19] I. Pastor, H. Hayes, and S. Bamberg, "A feasibility study of an upper limb rehabilitation system using kinect and computer games," in *Engineering in Medicine and Biology Society (EMBC), 2012 Annual International Conference of the IEEE*, 2012, pp. 1286–1289.

[20] M. Fraiwan, N. Khasawneh, A. Malkawi, M. Al-Jarrah, R. Alsa'di, and S. Al-Momani, "Therapy central: On the development of computer games for physiotherapy," in *Innovations in Information Technology (IIT), 2013 9th International Conference on*, 2013, pp. 24–29.

[21] B. Processing, "Seeme rehabilitation," Setpember 2013. [Online]. Available: http://www.virtual-reality-rehabilitation.com/products/seeme/what-is-seeme

[22] H. Sugarman, A. Weisel-Eichler, A. Burstin, and R. Brown, "Use of novel virtual reality system for the assessment and treatment of unilateral spatial neglect: A feasibility study," in *Virtual Rehabilitation (ICVR), 2011 International Conference on*, June 2011, pp. 1–2.

[23] J. Lee, "Smart health: Concepts and status of ubiquitous health with smartphone," in *ICT Convergence (ICTC), 2011 International Conference on*, Sept 2011, pp. 388–389.

[24] H. Demirkan, "A smart healthcare systems framework," *IT Professional*, vol. 15, no. 5, pp. 38–45, Sept 2013.

[25] M. Chan, D. Estve, C. Escriba, and E. Campo, "A review of smart homespresent state and future challenges," *Computer Methods and Programs in Biomedicine*, vol. 91, no. 1, pp. 55 – 81, 2008. [Online]. Available: http://www.sciencedirect.com/science/article/pii/S0169260708000436

[26] J. Bustos and K. Watson, *Beginning .NET Web Services Using C#*, ser. Beginning Series. Wrox Press Limited, 2002. [Online]. Available: http://books.google.pt/books?id=ToQGAAAACAAJ

[27] U. Technologies. Unity 3d. [Online]. Available: http://unity3d.com/unity/download

[28] M. Szpuszta and M. MacDonald, *Pro ASP.NET 2.0 in C# 2005, Special Edition*. Apress, 2006. [Online]. Available: http://books.google.pt/books?id=MWooIPGA4bkC